

Mr. Longridge. reports, which contained a great number of experiments upon that subject. Steel wire no doubt had been and could be obtained with a modulus of 22,000 tons, but that did not at all affect the general question; it merely affected the value of the “*c*,” which was one of the constants introduced into the formula. The formula was in such a general form that any modulus of elasticity, any radius of core or coil, and any dimension of gun, could be adopted. It would give the exact strain with which to lay on the wire if a uniform tension under fire were desired; or if uniform tension in laying it on was the object, another formula would give the exact strain under fire and at rest. It was perfectly general in form, and he sincerely hoped that the gun-makers would give it full and fair consideration, and put it to practical proof, instead of continuing to construct wire-guns by a tentative process. It was gratifying after thirty years to find that the views he then expressed as to the value of wire were being recognized; but it was grievous at the same time to believe that what was being done, and had been done up to the present time, had not been guided by theoretical and scientific considerations, but by a tentative process.

Mr. Woods. Mr. EDWARD WOODS, Vice-President, said all would agree that the Author had made a valuable contribution to the science of the construction of guns, and it must be gratifying to him to see that the subject was now receiving attention from those conversant with the details of the manufacture of ordnance. All present would join in the wish that the experiments now being made would be carried out to the Author's satisfaction, and would show the value of the system which he had been advocating.

Correspondence.

Mr. Longridge. Mr. LONGRIDGE observed that Sir Frederick Bramwell had taken exception to the calculation at p. 106 of the Paper, which represented the comparative power of the two guns, as obtained from Table XI., according to Noble and Abel's approximate method, detailed at p. 240 “Researches on Expansions;” that was to say,

	Foot-tons.
Chambered gun, 500 lbs. powder	17,357
Unchambered „ 413 „ „	30,103

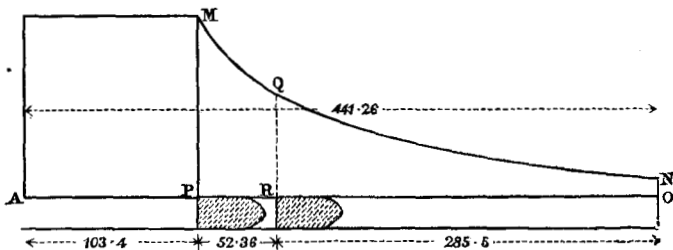
Sir Frederick Bramwell had challenged these figures, and found by his own method of using the Tables, an energy for the chambered gun with 500 lbs. = 26,357 foot-tons. The Author,

having examined the method of Messrs. Noble and Abel, had Mr. Longridge. come to the conclusion that, as applied to this gun, it did not give even approximately correct results; but at the same time he could not admit the correctness of Sir Frederick Bramwell's method. It was admitted by Sir Frederick Bramwell that the chambered gun was equivalent to an unchambered gun, lengthened by the difference between the actual length of the powder-chamber, and a length of 13-inch bore of equal capacity, say by 52·36 inches, as shown in Fig. 36.

He thus assumed 500 lbs. powder placed in the 103·4 inches, gravimetric density = 1, and the shot at P, and fired in a gun whose total length was 441·26 inches, or with 4·2 expansions.

Then, from Table XI. "Researches on Explosives," he got: work done per lb. of powder, 4·2 expansion, 84·70 foot-tons. Next he assumed the gun shortened to R, or 155·76 inches long,

Fig. 36.



and fired with a similar charge, and shot in the same position, which gave 1·5 expansion, and from the Table he obtained: work done per lb. of powder, 1·5 expansion, 31·986 foot-tons. Deducting this from the first gave the work done, represented by the area BQNO, and this he assumed to be the same as the work done by a similar charge fired in the space AR, density 0·6652, with the shot placed at R, and the expansion $\frac{441 \cdot 26}{155 \cdot 76} = 2 \cdot 833$.

It certainly would seem as if there should be no difference. In the first case there was the work done from R to O by 500 lbs. of powder, placed in AP and expanded to AR, whilst expanding from R to O. In the second there was the same weight of powder exploded in AR, and working by expansion, also from R to O. Were not the two equal? They were not. In the first case, the powder had expanded from P to R doing work; in the second, the expansion was without doing work.

Assuming the initial tension density = 1 to be 43 tons per

Mr. Longridge. square inch, the tension of the guns at R would be in the first case 18·62, and in the second 20·20 tons per square inch. But this was not the whole difference; the expansion curves did not coincide.

They might be worked out by Noble and Abel's formula (30), which might be put in the form

$$p = p_0 \left(\frac{x}{c} - 0.57 \right)^{1.074}$$

where

p_0 was the initial pressure,

p the pressure at x ,

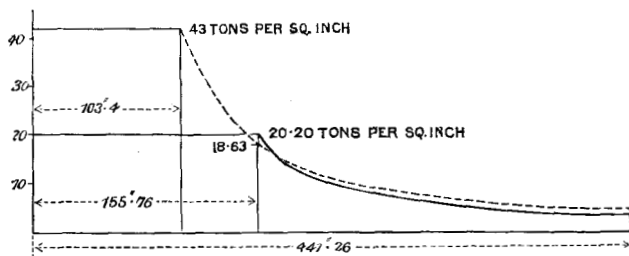
l the length of the charge.

Now x was always measured from the breech-end of the gun, and therefore, as l was different in the two guns, it was evident that the values of p , corresponding to x , could not be the same in the two guns.

The following diagram (Fig. 37), worked out by this formula, gave the expansion curves in the two cases:—

The dotted line was for the first case, and the full line for the second. It would be seen that, although at 155·76 the full line

FIG. 37.



was above, at about 162 it coincided with, and beyond that it fell below the dotted line. From this it was evident that the work done, as estimated by the first method, was greater than the actual work done, which was given correctly by the second method. If instead of using Table VI. the energy was calculated in both ways from the formula (34), the result would be, by Sir Frederick Bramwell's method of deduction, 52·714 foot-tons per lb., whilst by the direct method it would be only 46·771 foot-tons per lb. The direct method was indisputably the right one, and it there-

fore gave the total energy of the gun with 500 lbs. of powder Mr. Longridge. = 23,385 foot-tons. Proceeding by the same method with the unchambered gun, and 413 lbs. of powder fired at a density = 0·90, it would be found that the work done per lb. of powder was 81·09 foot-tons, whilst for 413 lbs. the total energy was 33,488 foot-tons.

The correct comparison was therefore—

	Foot-tons.
Chambered guns, with 500 lbs. of powder . .	23,345
Unchambered „ „ 413 „ „ . .	33,488

It must not be concluded that either of these guns would give these results in practice. These results represented the maximum possible effect that powder could give, and they must be multiplied by a fraction which Noble and Abel termed the “factor of effect,” and which varied according to the size of the gun and other conditions. They were therefore only to be considered as comparatives, between the chambered and unchambered systems. The comparison was largely in favour of the latter.

Mr. E. DUVAL, manager of the Fives-Lille Company, was unable Mr. Duval. to enter into the theoretical discussion of the Paper, the Author not having thought necessary to give the calculations upon which his formulas were based. Had Captain Schultz been alive he would doubtless have had something to say on the subject, but since his death at the end of 1882 the matter had not been pursued in France.

At the same time Mr. Duval would be glad to correct some errors in the Paper relative to the 34-centimetre gun constructed at Fives-Lille. The dimensions of this gun in cross-section were:—

	Millimetres.
Radius of inner surface of core at the powder-chamber . .	185·0
„ outer „ „ at the breech	330·0
The thickness of the tube was therefore	135·0
Radius of the outer surface of the coil	443·5
The thickness of the two layers of wire were therefore . .	113·5
The diameter of the wire employed was	3·0

The figures given by the Author for these dimensions, and which had been thus rectified, were taken from the report of the Chief of Ordnance, U.S.A., derived from Mr. Duval did not know what source. Those stated in the same report relative to the coefficient of elasticity of the materials employed were still more erroneous. The conditions of the specification prepared by the French Admiralty were:—

1st.—For the tempered steel forming the interior tube—breaking

Mr. Duval.

TRIALS OF FOUR 24-CENTIMETRE SCHULTZ GUNS.

Number and Description of Gun.	First Round.			Second Round.			Third Round.			Remarks.
	Charge.		Recoil.	Charge.		Recoil.	Charge.		Recoil.	
	Kgs.	Metres.		Kgs.	Metres.		Kgs.	Metres.		
I. Cast iron, not tubed, 7.2 metres long, with trunnion-hoop and breech-plate of steel. Before the trial, marks were made on the head of the bolts, on the nuts, on the breech-hoop, and on the coverings of the wires, to note if any displacement occurred. Also a gauge was established to measure any stretching of the bolts. The gun was placed on a timber cradle made for the purpose.	30	3.15		40	5.3		60	8.5		(The recoil in the third round was limited by the length of the platform, at the end of which were gabions to arrest the cradle. The shock of the cradle against the gabions sent them back 1 metre. The examination of the piece after each round showed it to be uninjured.
IA. Of similar construction and dimensions. Before firing similar marks were made as in No. I.	30	2.70		40	4.2		60	7.4		(The examination of the piece after each round showed it to be uninjured.
II. Of similar construction as No. I. but 6.6 metres long. Before firing similar marks were made as in No. I.	26	2.70		36	4.3		52½	7.0		(The examination of the piece after each round showed it to be uninjured.
IIA. Of similar dimensions as No. II., but with breech-plate and trunnion-ring of cast-iron. Before firing similar marks were made as in No. I.	26	2.70		36	4.2		52	7.3		(After the first round, an elongation of 2 millimetres was observed on two of the bolts. Also the head of a bolt was found to be depressed on one side to the extent of some hundredths of a millimetre, while on the other side it projected to the same extent. The second round did not affect the bolts already referred to; two other bolts were stretched, one 3 millimetres, the other 2 millimetres. Some sweating of oil was observed on the surface of the bolt-heads in the breech-plate.

strain, 60 kilograms per square millimetre (38·1 tons per square inch); minimum elongation, 5 per cent.; elastic limit, 30 kilograms per square millimetre (19·05 tons per square inch). The tube employed amply fulfilled these conditions.

2nd.—For the 3-millimetre steel wire—breaking-strain, 190 kilograms per square millimetre (120·65 tons per square inch); corresponding elongation, 2 per cent.; elastic limit, 133 kilograms per square millimetre (84·45 tons per square inch); elastic elongation, 7 per cent.

The several tests made both at the Conservatoire des Arts et Métiers, and at the works of the contractors, gave as the mean :—

Breaking strain	185	kilograms per square millimetre.
Corresponding elongation . .	2·8	per cent.
Limit of elasticity	123	kilograms per square millimetre.
Elastic elongation	7	per cent.

It would be seen that these figures were very different from those given by the Author, and his conclusions would necessarily need modification.

The trials of this gun were, to his great regret, stopped owing to the breaking, at the first discharge, of some bolts uniting the breech-piece to the trunnion hoop. Another gun, however, of 10-centimetres calibre, constructed at the same period for the French Admiralty, of similar materials, had so far (April, 1884) resisted perfectly the long and very severe tests to which it had been subjected during the last two years. He had every reason to believe that the 34-centimetre gun would behave equally well when the modification which had been decided upon had been carried out. This consisted in substituting for the bolts a steel strap. Unfortunately this would take some time.

Mr. Duval submitted some particulars (p. 152) of the trials of four 24-centimetre guns, constructed on Captain Schultz's system. The powder employed was that known as A $\frac{3}{10}$. In each case the Inspecting Committee (*Commission de Reception*) reported that the three rounds had not given rise to any observation of importance worthy to be recorded, and recommended that the guns should be accepted.

Dr. W. E. WOODBRIDGE agreed with the Author that it was important the question of strains should be mathematically considered, and that Mr. Brooks had treated the subject upon correct principles. It was evident, however, that calculations must be applied to ascertained data, and therefore that the experimental determination of the properties of the materials to be used in gun-
Dr. Wood-bridge.

Dr Wood-bridge. construction lay at the basis of the whole subject. It was of course necessary, too, that all the elements of the problem should be taken into account. From the neglect of one or other of these necessities doubtless arose what were called discrepancies between theory and practice. The calculations of which the results had been presented in the Paper seemed to have been made without reference to the deformation of the wire (whether round or approximately rectangular), resulting from the imperfect contact of surfaces pressed together by the radial strains generated in winding. The effect of the neglect of this element in computation would be an underestimate of the strain upon the interior coils of a gun, as compared with those of the exterior. The extent of this error must be experimentally determined. This was said of guns not soldered. Evidently if the vacuities between the wires were filled with a soldering metal, the several layers would be brought more nearly into the condition of perfect contact. Perhaps a more serious oversight consisted in taking what might be called the working-pressure of the gun as the point at which it was desirable that the strains on the wound wires should be uniform. The highest resistance which the materials were capable of affording was procured when the whole were brought into uniform strain at the maximum strain they were able to withstand. In providing this highest resistance as a safeguard against rupture by abnormal strains, the lesser strains of working pressures were equally well provided for. Inasmuch as steel wire of suitable size might be produced having an elastic limit of 120,000 lbs. per square inch, while retaining an extensibility indicated by the capability of winding around a wire of the diameter of its own diagonal dimensions, the tension of winding might be carried much higher than the Author seemed to approve. True, very high tensions from the cylinder within the coil necessitated very great resistance to the contractile effort of the wire; but this might be advantageously provided by means of the metal serving to give longitudinal strength to the gun. The Author had mentioned four styles of gun-construction in which wire was employed, as having been proposed by Dr. Woodbridge to the late Board on Heavy Ordnance, appointed by Act of Congress. The one placed second on the list was briefly described, with the omission of one or two very important items, in the following words:—"A steel gun, composed of an inner steel tube overlaid with longitudinal bars, and then wound round with steel wire under high tension, and finally soldered." To this it should be added that the longitudinal bars (covering about one-half the

length of the tube) formed a cylinder of closely fitted staves, and that they were made of cold-wrought steel, having high elastic limits of extension and compression, while they preserved a capability of considerable elongation beyond the elastic limit. This mode of construction differed markedly from those recently essayed elsewhere than in the United States, so far as they had come to Dr. Woodbridge's knowledge, first, in providing a resistance to the constructing force of the wound-wire, so high that the tensile strain upon the latter was in no part changed to compression in winding, and that the interior cylinder was never released from compression, even in firing; and, secondly, by the union of the wires by soldering. The importance attached to the first-mentioned peculiarity arose from the avoidance of the disintegrating tendency of high reversed strains, under such circumstances as existed in this class of construction. One item of the advantages of soldering had already been mentioned, and need not be repeated. In addition to the general solidity, or resistance to displacements which it imparted to the structure, there was, in his view, a specially important feature of this kind. For the purpose of readily presenting this idea, suppose the wire could be frictionless, presenting all the other properties of a suitable gun-wire. Employing this, there would, of course, be no such possibility as varying tensions in a continuous wire, whether in the first layer or in other parts of the coil. But this, whatever might be its result, was impossible. There was, however, a momentary approach to that condition in the firing of an unsoldered wire-gun. The vibratory motions then set up partially freed the wires from the restraints of friction, and they were allowed to "creep" in the direction which tended to relieve them from the heavier strain. This would have no injurious result were the strains uniform throughout the whole length of the helices which enwrapped the tube; that was to say, if pressures were the same in all parts of the bore they surrounded, for then it would amount to nothing more than an equable distribution of strains. The case was, however, far otherwise. The heavy strains near the breech sought to relieve themselves by drawing the wire in that direction, and the original tension was there impaired. This action was, of course, prevented by soldering. A very obvious addition to the advantages of the process was the security with which the ends of the wires were fastened, and the prevention of the consequences of the accidental cutting or breaking of a single wire in an unsoldered gun. Perhaps the citation of an experiment made at the Washington Navy Yard might allay

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Dr. Wood- the suspicion of some that the high tensions advocated might not
bridge. be maintained by the wire, especially when the guns were subjected to vibrations as in firing. A wire 0.15 inch square was extended with a tension of slightly more than 90,000 lbs. per square inch, maintained by a suspended weight of more than 2,000 lbs. Fine marks were placed upon the wire 100 inches apart, and corresponding marks upon a steel rod at its side. A hard-wood hammer, actuated by the power driving the machinery of the shops, delivered blows upon the strained wire at the rate of from four hundred and fifty to five hundred per minute, during working hours, for more than two months. No yielding or elongation could be detected. Two guns of the style mentioned above were now being constructed for the United States Government, and in due time might be expected to furnish the kind of instruction that was after all the most convincing, namely, experimental. It was to be regretted that the Author had not given an account of the trials of his 3-inch gun, to which he alluded in support of his opinion that a cast-iron gun tube might, without disadvantage, be subjected to a compression many times exceeding that within its elastic limit. The Author had referred to the results of experimental wire-gun construction in the United States, and it might be proper that Dr. Woodbridge should mention some facts in that connection. In July 1850 he called the attention of the Ordnance Department of the United States to a plan of construction embodied in a small gun of his invention and production, its linear dimensions being one-third those of the standard 6-pounder field-gun.¹ It was made of flat iron wire having a cross-section of $\frac{1}{8}$ inch by $\frac{1}{4}$ inch, wound upon an iron tube, and brazed. Before being bored to calibre or turned on the exterior, it was fired with a charge consisting of rifle-powder, a wad and leaden shot filling the tube, to make a rough test of its strength, and also for the purpose of expanding its bore so as to bring out the resistance of its metal to an extent likely to prevent further enlargement under ordinary strains. It was finished to a weight little less than three-fourths that of a bronze-gun of the same calibre having the model of the 6-pounder, which was provided for a comparative test. The reduction of weight was made by a proportionate reduction of the thickness of the metal in the different parts of its length. It was subjected to several days' continuous firing, but the experiment relied on as a demonstration

¹ See Copies of documents given in the Report of the Chief of Ordnance, 1872, p. 159.

of its superior strength was a comparison of the resistance of the two guns to hydrostatic interior pressure. The bronze-gun was ruptured at an indicated pressure of a little more than 32,000 lbs. per square inch. The wire-gun withstood the same pressure without visible change. In 1862 a small steel wire-gun was made at the Navy Yard, Washington, D.C. Nineteen wires $\frac{1}{16}$ inch square were wound at once. The bore was 2.5 inches in diameter, measured on the "lands," or 2.7 inches measured in the grooves, and the exterior diameter 5.4 inches, making the thickness over the grooves just one-half the corresponding diameter of the bore. No lining-tube was used in its construction. The wire was wound on a mandrel of bronze of the same composition as the soldering metal, which commingled with it in the process of soldering and filled the space within the wound wire. The lining of the bore was therefore of the same material with the solder. The weight of the gun, exclusive of the trunnion-hoop, was 149 lbs. The first test of this gun was made under the control of the late Admiral Dahlgren, with charges of 1 lb. of powder, and a 4-lb. projectile having an expanding metallic sabot. The inventor suggested the use of a heavier projectile, but was overruled by the Admiral. This test was carried only to the one hundred and fifth round. A tangential specimen cut from the muzzle of the gun showed a tensile strength of more than 108,000 lbs. per square inch. The gun was subsequently sent to the late Mr. Edwin A. Stevens, of Hoboken, for further trial, the manner and extent being left to his discretion. Mr. Woodbridge had not ascertained the extent of the trial by Mr. Stevens, but upon applying for the removal of the gun for the test afterward made at Springfield, Mr. Stevens informed him that he was "Satisfied that it could not be burst by any charge of powder and projectile that could be put into it." In 1865, by the direction of the late General Dyer, then Chief of Ordnance, it was submitted to further test at the Springfield Armoury under command of Colonel Laidley. It was there fired thirteen hundred and twenty-seven additional rounds, the charge of powder being constantly 1 lb., and the projectiles either $7\frac{1}{8}$ or $10\frac{3}{8}$ lbs., seven hundred and ninety rounds of the former, and five hundred and thirty-seven of the latter. The following was a portion of Colonel Laidley's report:—"The greatest enlargement of the bore, in the rear of the seat of the shot, caused by the one thousand three hundred and twenty-seven rounds of excessive charges, is only seven-thousandths of an inch, and there are, as yet, no indications of the gun giving way in any part." As a practical test of transverse strength this

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trial was one of peculiar severity. The brazed wire had no support from a lining-tube, and the cross-section of its metal compared with that of the United States 3-inch wrought-iron rifle, fired with the same charge and weight of projectile, was but as 1 to 3·8. The gun was fired from a 6-pounder carriage of old and heavy pattern, heavily reinforced with iron to give it the necessary strength; the whole weight (probably not less than 1,200 lbs.), practically, as related to strain in recoil, being added to the gun at the trunnions. In accordance with the recommendation of the Chief of Ordnance, and of a Board of Officers appointed under an Act of Congress, approved June 6th, 1872, a brazed wire-gun of 10-inch calibre had been constructed under his direction at Frankford Arsenal. The fabrication of this particular gun was intended as a means of instruction and practice preliminary to the manufacture of a larger gun; but Congress had added to the work to be accomplished by means of the appropriation asked for by the Chief of Ordnance for this special work, much more largely than to the appropriation, so that it became impracticable to go on with the larger gun. The brazing of so large a mass of wire (about 15 tons) was an operation quite unprecedented, and it might be left to those who had carried out processes so widely varying from anything practised in the arts to say how great were the difficulties of executing the best laid plans in the first endeavour, and whether it was a matter of surprise that the first product should fall short of perfection. It was the gun last mentioned that fell under the Author's condemnation; and it must be admitted that it was by no means a perfect specimen of its style of construction, nor was it ever supposed to be such.

At the ninety-third round, with a charge of 80 lbs. of powder and a 400-lb. projectile, "the gun parted under longitudinal strain," said the record of the Board, $26\frac{3}{4}$ inches from the bottom of the bore. The powder employed had been selected for its "briskness," with Dr. Woodbridge's approval, and the pressure recorded by the "Woodbridge" gauge, being used alternately with the "Rodman," was 74,400 lbs. per square inch, or, as properly stated by the Board, "about 80,000 lbs. per square inch as measured by the Rodman gauge." Briefly, the defect of the gun was imperfect brazing, consequent upon insufficient heat at the lower or breech part of the gun. Bronze had penetrated everywhere, not a spot being found, in cutting up the gun, which it had not reached. But the lower portion of the gun, except superficially, had been brazed only by "liquated" metal, which alone could flow at the temperature of that part of the mass. Below the plane at

which the temperature precluded the flow of the bronze in its entirety, the small spaces between the wires were not perfectly filled; and immediately below that plane the interfused bronze held its position, so far as was possible, only by capillary action, until it cooled. It was in this plane of most incomplete brazing that the gun parted. Notwithstanding this result, the abundant heating-capacity of the furnace and the reliability of the tests of the temperature of the different parts of the gun, when properly adjusted and employed, were demonstrated; and no room for doubt was left, at least in his mind, that the original plans, fully carried out, would have assured complete success. One important feature of the construction of this gun seemed to have been overlooked by the Author, who evidently regarded it as a specimen in which the wire had no initial tension. He might have learned from the source of information to which he referred that the gun was cooled from the interior, and that the indications of initial strain, manifested by the compression of the interior, were most clearly given. The bore was contracted, as the result of firing, even at the seat of the charge. Any discussion of the relative advantages of this mode of construction would extend this communication too far. It might be permissible to add that the late Board on Heavy Ordnance who unanimously recommended the construction of two styles of gun presented by him, also recommended, by a majority vote, the fabrication of a brazed wire-gun.

Mr. LONGRIDGE in reply to the correspondence said, with reference to Mr. Duval's remarks, that the difference of the dimensions was chiefly in the inner diameter of the powder-chamber, and the effect of this, if introduced into the calculation, would be considerably to increase the tensions of the coil under fire, and the compression of the case at rest, thus showing the gun under worse conditions than actually considered in the Paper. The substitution of the steel strap for the bolts to resist the longitudinal strain, was no doubt a very great improvement. Dr. Woodbridge said that the calculations in the Paper seemed to have been made "without reference to the deformation of the wire, resulting from the imperfect contact of surfaces pressed together by the radial strains generated in winding." In this remark he was mistaken. It was the very contact of one wire with another that transmitted the strains, whether the gun was at rest or under fire, and the effect of this contact, and the normal forms arising from it, had been fully taken into account. The filling the interstices, if there were any, with solder, would not at all increase the strength of the gun. There was nothing in the remarks of Dr. Woodbridge in his

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Mr. Longridge.

Mr. Longridge. present communication beyond what he had so often stated on other occasions, and the Author could not see that they in any way tended to modify the conclusions respecting Dr. Woodbridge's gun, which he had embodied in the Paper itself.

25 March, 1884,

EDWARD WOODS, Vice-President,
in the Chair.

The discussion upon the Paper by Mr. Longridge, on "Wire-gun Construction," occupied the whole evening.
